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# COMPARISON BETWEEN MINOR DESTRUCTIVE TESTS RESULTS AND FINITE ELEMENT MODELS: THE CASE OF A SANDSTONE MASONRY WALL TESTED IN LABORATORY.

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**Key words:** masonry, numerical modeling, flat jack.

**Abstract.** *This work is a comparative between stress and strain results obtained from Minor Destructive Tests (MDT) for several load tests on a sandstone masonry wall performed in laboratory, and the numerical results obtained from finite element models, in order to draw conclusions about the challenges and kindness of the experimental technique employed.*
*Laboratory tests correspond to simple flat jack tests performed on a masonry wall.*
*In regard to the model, a macromodel has been used, assuming it consists of a single isotropic material with elastic behavior, pretending to be a first approximation from which the results can be refined. The parameters characterizing the material have been taken from laboratory results obtained from double flat jack tests. It is therefore a two-way analysis, where laboratory results are compared with those obtained from numerical calculation, and these, in turn, are fed with previous results.*
*By numerical modeling we obtain the stress distribution on the wall, resulting, first, from the load application, and after, induced by the pressure on the flat jack. Thus, we can compare the stress distribution resulting from the application of the load with the values obtained from the simple flat jack tests to validate them, and then study the evolution of stress and strain the wall during the test in order to achieve a better understanding of the process.*

## 1 INTRODUCTION

The purpose of this work is to do a comparison between the experimental results obtained in the laboratory, concerning the state of stress and deformations of a masonry wall, and the theoretical ones, obtained from numerical modeling. The laboratory tests carried out were part of the Doctoral Thesis "Theoretical - Experimental Research about Minor Destructive Tests (MDT) applied to the Mechanical on-site Characterization of Historical Masonry Structures" [1].

For this, the study is focused on a masonry wall modeling the simple flat jack tests [2], [3], [4], [5], [6], [7].

With this aim, a macromodel of the wall has been used, assuming it consists of a single homogeneous material [9], [10], [11]. The parameters characterizing the material have been obtained, in turn, from the laboratory results from the double flat jack test. It is therefore an analysis, bidirectional, in which laboratory records are compared with those obtained from numerical calculation, and these, in turn, fed with previous results.

## 2 TEST DESCRIPTION

The simple flat jack test, whose results are intended to be validated in this study, consists of a minor destructive test to obtain an approximate stress distribution in a structural element. To do this, the steps are:

- Mark on the wall two rows of control points. Measure the distance between them.
- Make a groove on the wall in the middle plane between the two rows of the control points.
- Measure the new distance between points (which will be closer after the groove's execution).
- Introduction of the flat jack in the groove and pressure's applying.
- Measure the distance between the points of control until it recovers the initial.

According to the test's methodology, the pressure applied on the flat jack at the moment in which the distance between the control points is recovered can be related with the existing stress on the wall before the test.

For this study, this test has been reproduced in the laboratory by applying a vertical load on a masonry wall. In Figure 1 some photographs of the test developed are shown.

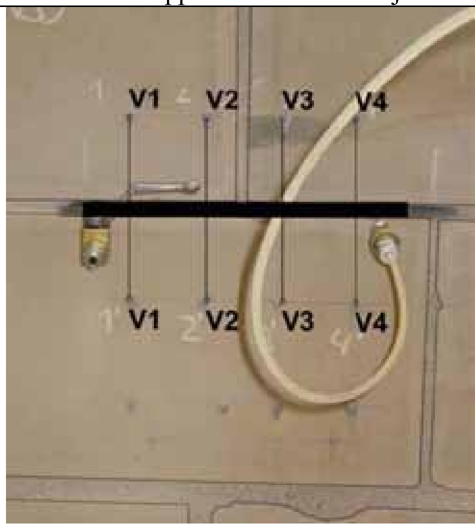
General view of the masonry wall.

Measure of the initial distance between the control points.

Implementation of the groove.

Pressure's application on the flat jack.

Measure of the distance's evolution between the control points.




View of the groove, the flat jack and the control points considered.

Figure 1. Photographs of the laboratory tests carried out.

## 3 INITIAL DATA

To model the behavior of the wall it has been considered that it consists of a single linear material behavior, elastic and isotropic. This has been defined by the values of the Modulus of Elasticity (E) and Poisson's ratio ($\nu$) obtained in the laboratory from double flat jack tests performed in the sandstone masonry. The values used in the calculation are:

$E=3{,}11.10^9$ N/m$^2$

$\nu=0{,}19$

The density ($\rho$) was estimated from a specimen of sandstone, which dominates the wall material under study. The value obtained was:

$\rho=2227$ kg/m$^3$

The loads considered have been the weight of the wall and the load applied on the upper side of the wall. To determine the weight, the value of the density referenced was taken, and to determine the vertical load it was taken into account the load supplied by the hydraulic jacks and the beam's weight that is used for a better distribution of loads. With the addition of these values the load applied is:

P=90.430,4 kp=904.304 N

With this load it results the following pressure applied on the upper side of the wall:

p=2.917.109,68 N/m$^2$

## 4 CALCULATION METHODOLOGY

For the numerical modeling of the experiments conducted in the laboratory, the program used has been ANSYS v11 [8].

The first step given was to define a model with the geometry of the masonry wall tested in laboratory whose main dimensions are shown in Figure 2.

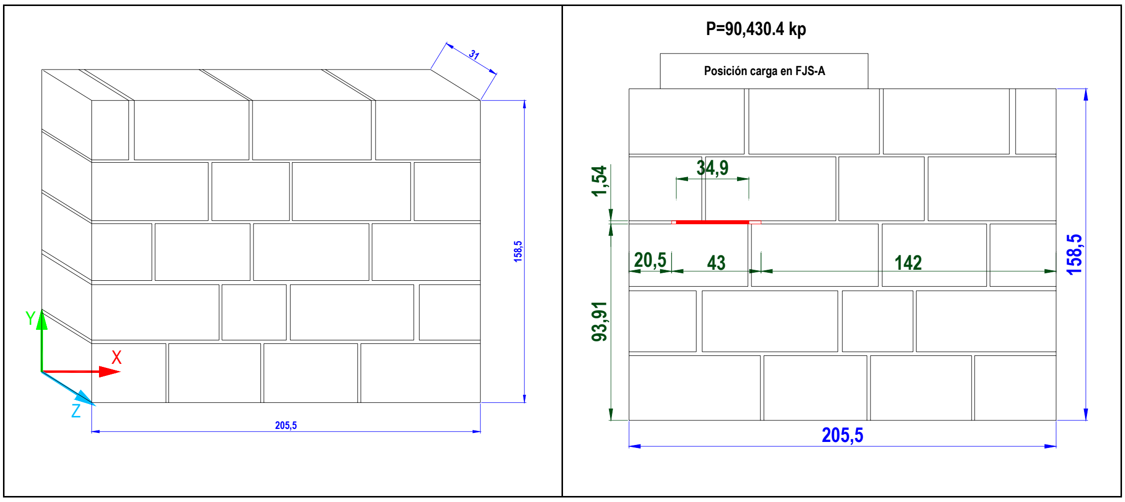



Figure 2. Wall's geometry (cm).

The next step was to define a space discretization which consists on dividing the solid wall in elements within the different parameters are evaluated (stresses, displacements, etc). The element's types used were SOLID45, when the discretization is performed with hexahedral elements, and type SOLID92 for tetrahedral elements. In both cases these elements are three dimensional, whose degrees of freedom correspond to the movements in three directions at each of its nodes (UX, UY, UZ).

As boundary conditions, it is considered coerced the displacement in the three directions on the base of the wall.

With these considerations three different approximations have been developed. A first one considering a hexahedral groove covering the entire wall's wide, a second one considering the real groove and jack's shape with the jack's pressure applied on all its surface and a third one considering the jack's pressure applied only on a fraction of its surface.

In Figure 3 images of the models used are shown. The first model was used in the first calculation (considering a hexahedral groove) and the second one for the other two (considering the real shape of the groove). The real shape for the groove and for the flat jack was obtained after the laboratory test, removing the upper part of the wall marking the outline of both the groove and the flat jack. In Figure 4 these outlines are represented.

In the three cases the steps given have been the followings:

- Obtaining the stress distribution after the application of the load on the upper face of the wall.
- Implementation of the groove (by removing the corresponding elements).
- Flat jack's pressure application by steps.
- Stress and strains' distribution for each pressure step.
- Comparison between the results obtained from the numerical calculations and the ones obtained in laboratory.

Each of these steps will be described in detail in the next sections.

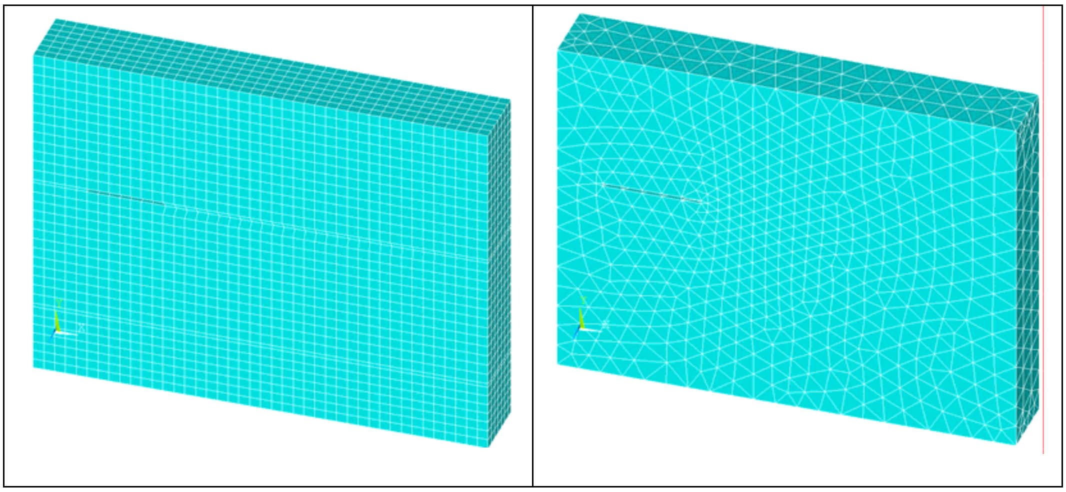


Figure 3. Models used for the calculations.

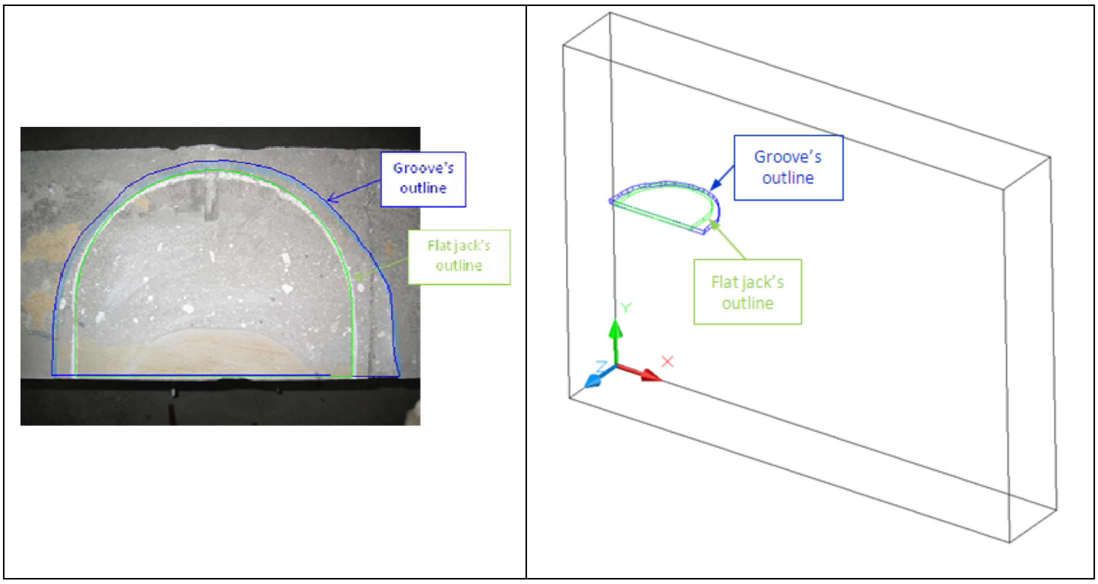



Figure 4. Groove and flat jack's outlines.

## 5 INITIAL STRESS DISTRIBUTION

As explained above, the first step given was to obtain the stress distribution after the load's application in order to know, before the calculation, the approximate result we should arrive to. The results obtained are shown graphically in Figure 5.

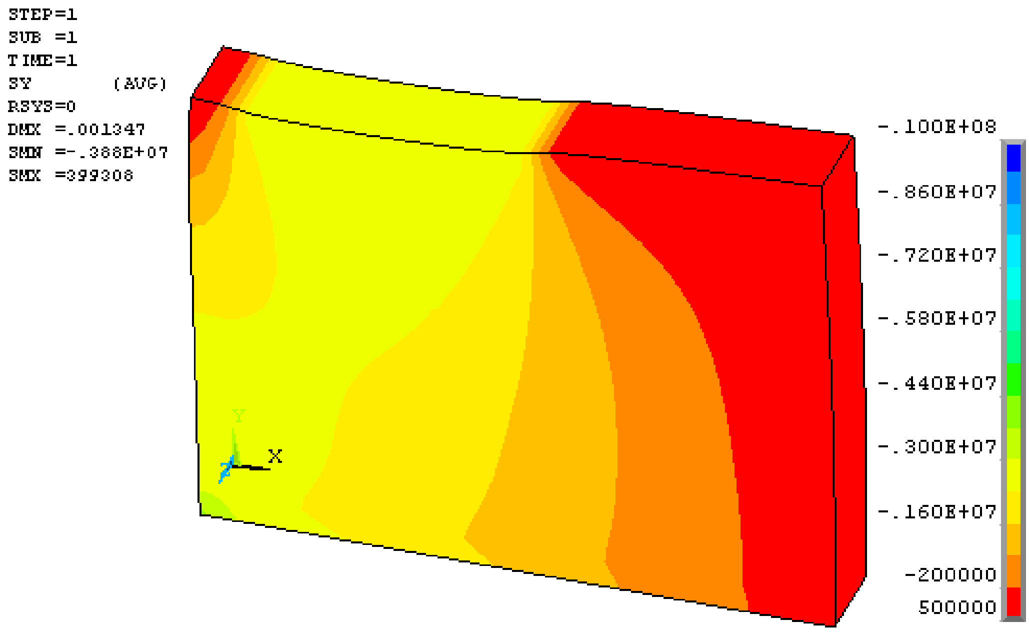



Figure 5. Stress distribution after the load's application.

From the calculations done we obtain that the approximate stress at the groove's height is 24,0.$10^5$ N/$m^2$. According to the test methodology, this value should be similar to the pressure applied to the flat jack for which the distance between the control points is recovered.

## 6 IMPLEMENTATION OF THE GROOVE

In the calculations the implementation of the groove consists on the elimination of the elements corresponding to its volume. With this, we obtain a new stress distribution and a vertical displacements distribution in which we can appreciate the decrease in the distance between the control points.

In Figure 6 we represent the stress distributions for the two models used, once the elements of the groove have beene removed, and in Figure 7 the distributions for the vertical displacements.

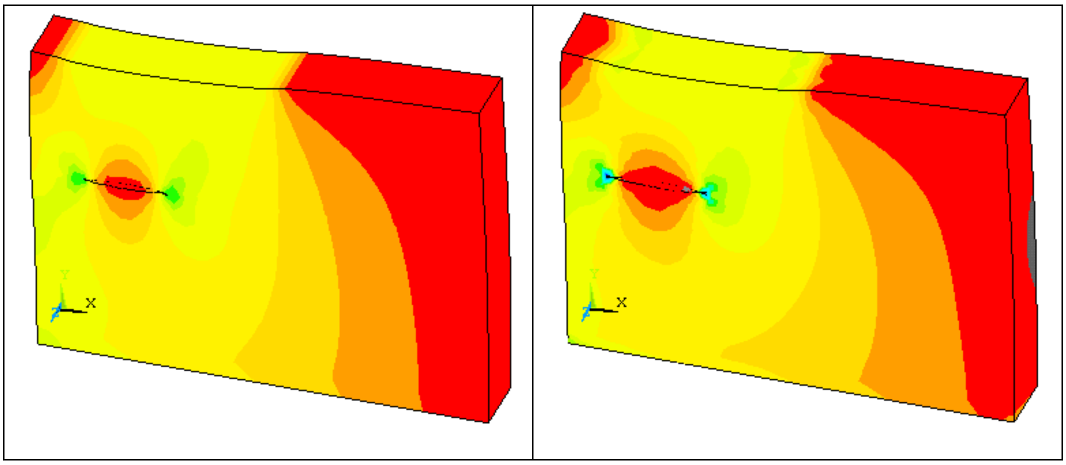


Figure 6. Stress distributions after the implementation of the groove for the two models: hexahedral groove and real shape of the groove.

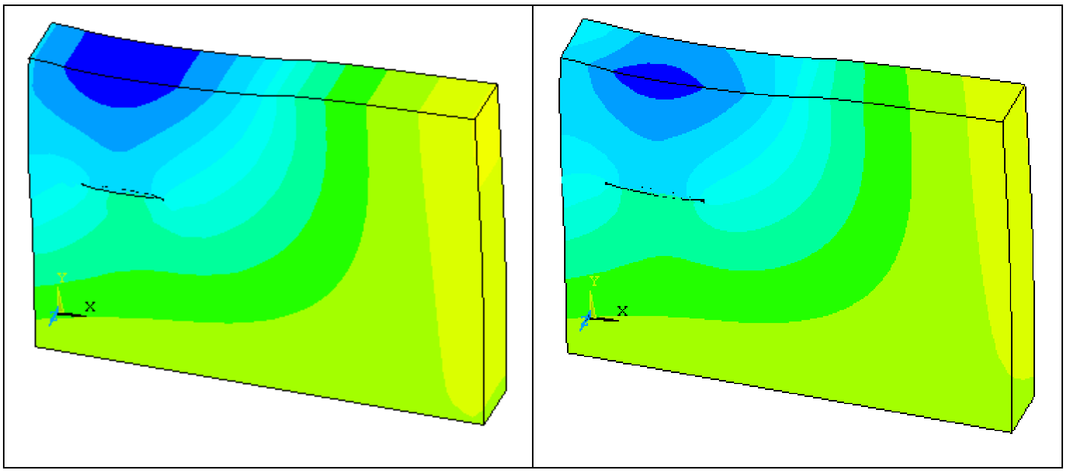


Figure 7. Vertical displacements distributions after the implementation of the groove for the two models: hexahedral groove and real shape of the groove.

## 7 PRESSURE'S APPLICATION AND STRESS DISTRIBUTIONS OBTAINED

In the next calculation's steps given, a pressure is applied on the flat jack's surfaces. In these steps is when the differences between the three calculations done are more obvious. In the first one the pressure is applied in a hexahedral surface which covers all the wall's wide, in the second one the pressure is applied only in the surface that corresponds to the real shape of the flat jack, and at last, in the third calculation, the pressure is applied in a portion of this surface which corresponds to an approximation of the contact surface obtained in the laboratory tests. In Figure 8 the area of the pressure's application is represented for each case.

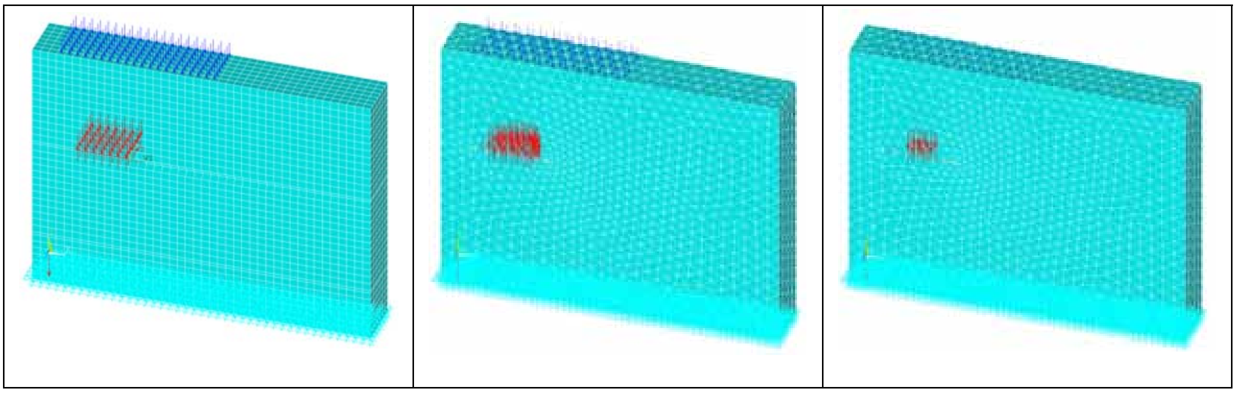


Figure 8. Different areas considered for the pressupre's application

For the third case, the surface in which the pressure is applied was obtained from the laboratory test, placing a tracing sheet on the flat jack so that the pressure's surface would be represented on it. In Figure 9 we can see the area used for this calculation.

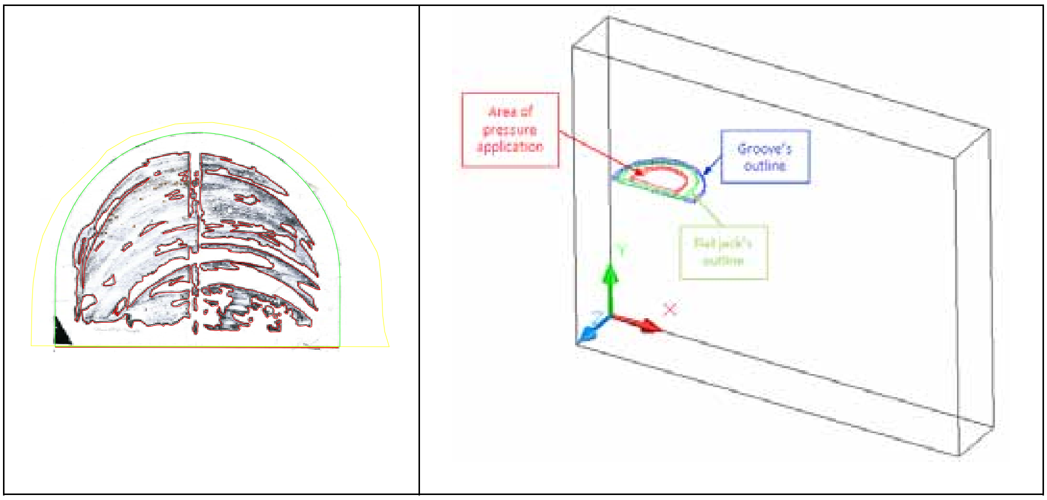



Figure 9. Area of pressure application

For these three different hypotheses we have obtained the stress distributions for two flat jack's pressures: one corresponding to the initial stress obtained at the groove's height ($24{,}0.10^5$ N/m$^2$), which should be the value for which the distance between the control points should be restored (Step 9); and other corresponding to the real pressure for which this distance coincides with the initial one measured (Step 10).

In Figure 10 the results for the stress distributions in each case are shown.

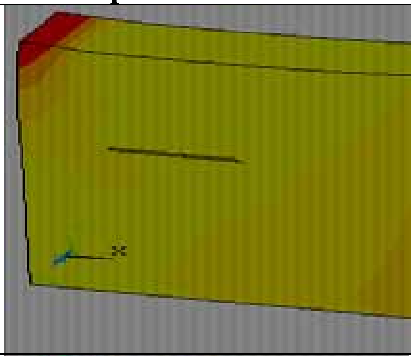
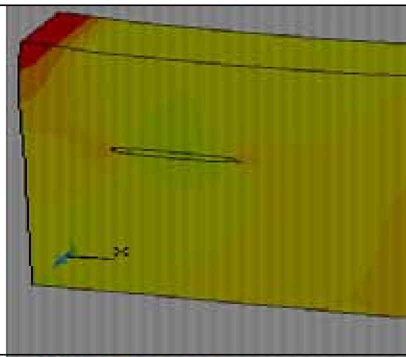
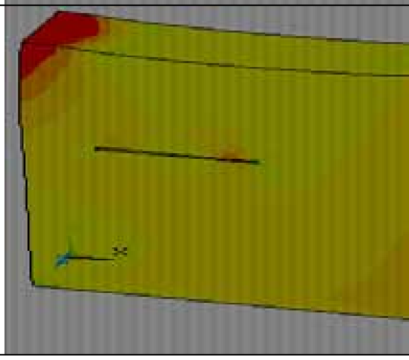
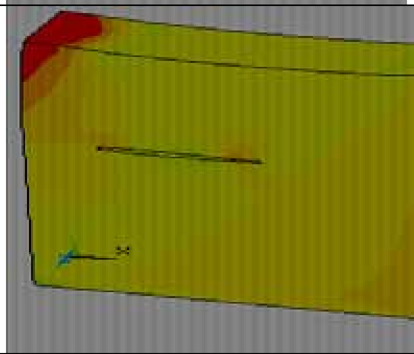
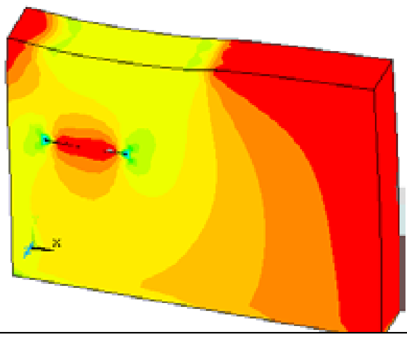
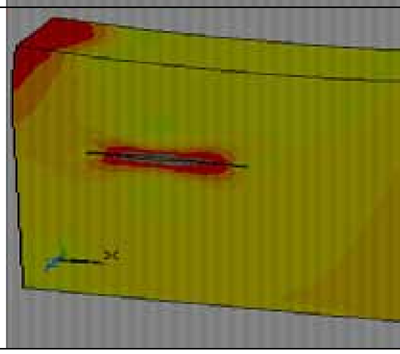
| | **STEP 9**<br>**p=24.10$^5$ N/m$^2$** | **STEP 10** |
|---|---|---|
| **First calculation** |  |  |
| **Second calculation** |  |  |
| **Third calculation** |  |  |

Figure 10. Stress distributions for the three calculations done for two flat jack's pressures.

Analyzing the different figures, we can notice that for Step 9, the stress distribution in the first and second calculations is similar to the initial one, even if the distance between the control points is not completely recovered. It doesn't occur the same in the third case, in which an area with tensile stresses appear around the groove.

In what concerns to Step 10, results for the first and second calculations are closer although it should be noticed a compression area around the groove, due to the pressure applied with the flat jack, bigger, and therefore less realistic, in first calculation. Again the stress distribution obtained with the third calculation doesn't reproduce the expected behavior of the wall during the test.

## 8 COMPARISON BETWEEN EXPERIMETAL AND NUMERICAL RESULTS

In the test carried out in laboratory, the resulting stress was $34{,}9.10^5$ N/m$^2$, value higher than the theoretical one expected ($24.\ 10^5$ N/m$^2$). Comparing it with the results obtained from the numerical simulation, we can conclude that the first approximation gives us a very similar value ($35.\ 10^5$ N/m$^2$) so it could be used to get a sufficiently accurate result.

However, the second calculation carried out gives us a nearest result to the theoretical one ($30.\ 10^5$ N/m$^2$).

The third calculation is not useful to simulate the test as it considers an area in which the pressure is applied too small to reproduce the real behavior of the wall during the test.

## 9 CONCLUSIONS

After all the calculations done, we can conclude that the simple flat jack test gives a reasonable result for the stress level in a masonry wall.

In what concerns to the numerical simulation, the results are also sufficiently. Anyway, it is important to emphasize that the calculation carried out is a first approach, having used a macromodel and considering an isotropic material with linear elastic behavior. It is expected that considering plastic behavior, nonlinearity and anisotropy, would improve the accuracy of the results achieved.

Even if the results obtained are not exactly the existing ones, we should not forget that the objective of this type of test is to obtain an order of magnitude of the stress situation of the wall with the least destructive testing possible, without considering it necessary, in general, to get the exact value of the stress at one point.

It is remarkable that in onsite tests the results would be even more accurate, taking into account that effects due to boundary conditions, as the size of the wall, disappear in a real wall.

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